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COLOR VISION DEFICIENCIES IN ARMY FLIERS

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UNITED STATES ARMY MEDICAL RESEARCH
AND DEVELOPMENT COMMAND

ABSTRACT

Normal color vision has historically been an intrinsic part of the physical standards maintained for military and civilian aviators and aircrew members. This *a priori* requirement has not been challenged due to the abundant number of applicants versus the number of such positions available. There is no longer a surplus of such personnel. In view of the percentage of the male population affected by imperfect color vision, this standard contributes significantly to the number of applicants rejected. An easement in this standard could be immediately converted to a larger number of otherwise qualified applicants. This paper deals with a review of some color tests and a testing procedure employed to determine the number of color anomalous fliers in Army aviation. Data collected indicate that this requirement may be unnecessary and that a new philosophical approach is long overdue.

APPROVED: Robert W. Bailey

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Lt Colonel, MSC
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Color Vision Deficiencies in Army Fliers

Normal color vision has historically been an intrinsic part of the physical standards requirements for military and civilian aviators and air crewmembers. This a priori requirement has not been challenged due to the abundant number of applicants versus the number of positions required in aviation. There is no longer a surplus of such personnel since each year we find a greater number of people becoming engaged in aviation. This is demonstrated by the fact that during the period 1945-1961 the number of certified civil pilots increased over 1/2 million.

In the Army about 50% of our applicants for aviation training who are rejected due to a failure to meet physical standards are rejected because of visual defects. In view of the percentage of the male population known to be affected by imperfect color vision, this requirement alone appears to contribute significantly to the number of applicants rejected. It is obvious then that an easement of this standard could result in a larger number of otherwise qualified applicants. This is not a new concept; in fact, it was presented to the 1954 AGARD Meeting by Bouman and Walraven(1). When the aviator's color vision requirement is related to flight safety and mission accomplishment it is difficult to maintain the philosophy that selection be continued according to those color vision tests that have been designed to be dichotomous in their selection.

Few of the navigation, in-flight operation and airfield control procedures that are encountered in modern aviation depend upon the particular skill of perfect color vision as they once did in the pre-electronic era. Further, even the complex color codes of the electronic industries do not appear to present a problem to those subjects classified as weak anomalous observers. Bouman's research(2) has indicated that, "even beyond a certain number of mistakes in the reading of the Ishihara plates, still a fraction of the subjects are good code-readers." Therefore there is a need for a color vision standard and test methodology that is more closely related to flying safety and mission accomplishment. Further support for such a test and modification of the color vision requirements is found in the work of Walraven(1), and that of Heath and Schmidt(3). Walraven(1) found the color naming by normals unstable under adverse conditions of duration and intensity. The paper by Heath and Schmidt(3) is also of particular interest because of the similarity of the experimental design to the actual conditions found in aviation. Their conclusions were based upon the effects of presenting short flashes of colored lights that were to be identified properly while intermixed with other nonsignal background lights. The subjects for this study included both anomalous and normal observers.

In order to effect maximum manpower utilization it would appear that tests for color vision that provide quantitative information analogous to visual acuity would provide a better basis for selection. There have been efforts to develop this type of test, but none are universally acceptable. For example the Inter-Society Color Council USA - Color Aptitude Test, authored by Drs. Dimmick and Foss(4) has been considered by some researchers(5) to be of questionable value in predicting color discrimination ability and yet promising enough to be examined further by another(6). As early as 1923 Verrey and Wolffin(7) predicted that anomaloscope findings might yield quantitative data for color defects and Trendelenberg and Schmidt(8) employed matching ranges to classify the degree of color anomaly. This type of anomaloscope data has yet to be compared to color naming capability required for signal color recognition. It appears then that quantitative tests of color vision are either not yet available, or those that are available have not yet been sufficiently validated.

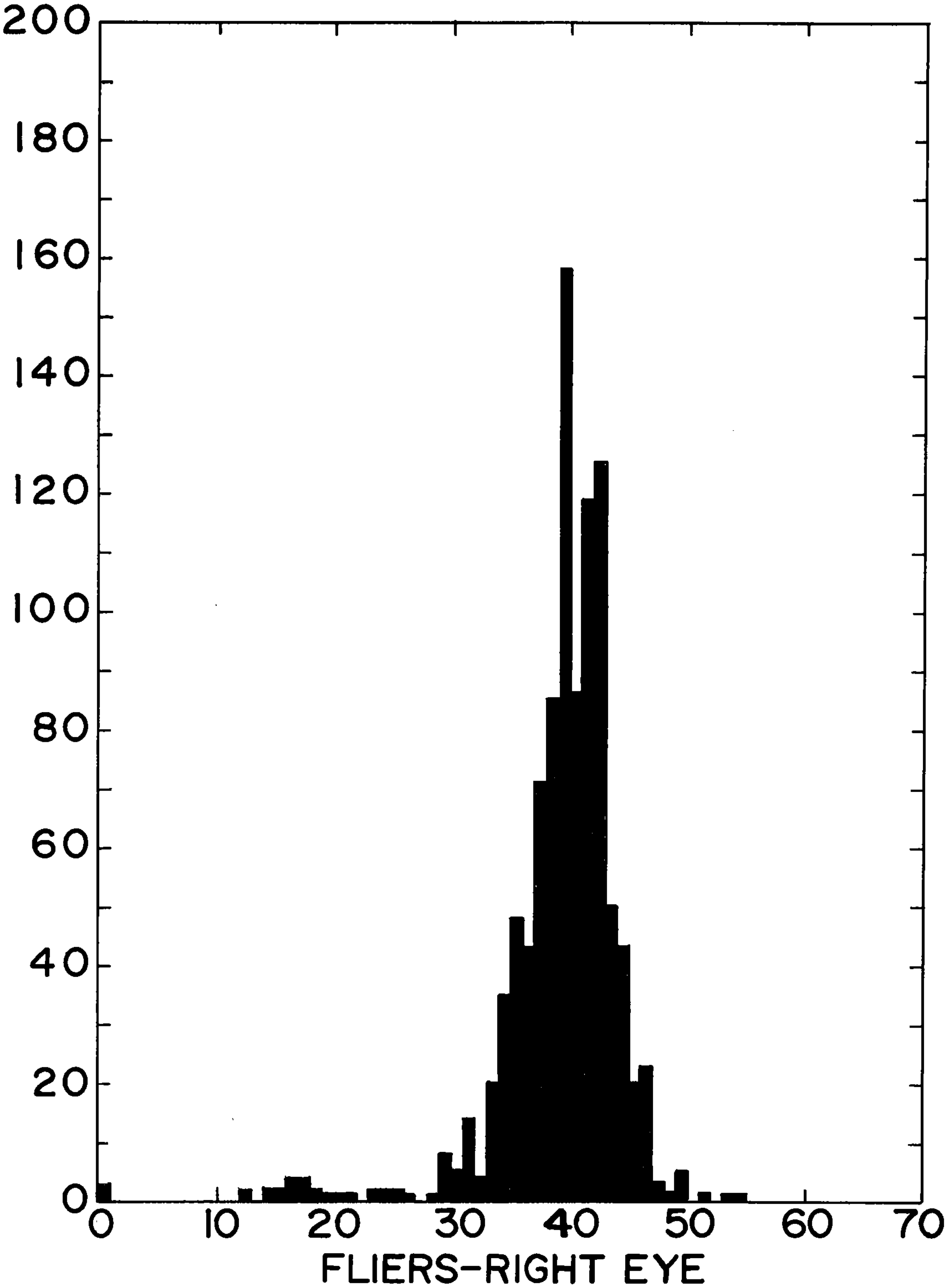
Therefore, the point of departure for color vision research in Army aviation medicine was selected to be the color vision evaluation of aviators and air crewmembers now actively flying aircraft. The ultimate goals of such a research project to be the establishment of color naming requirements and a quantitative testing method for selection against these new standards. In view of the reported efficiency of the Nagel anomaloscope in separating normal from anomalous observers(9) it was decided to employ this type of instrument for color vision testing. Our particular instrument, a Nagel anomaloscope, Model 1, Schmidt and Haensch, Berlin, Germany, 1963, permits color vision testing by blending spectral colors of a red of 670.8 millimicrons and a green of 546 millimicrons to match a yellow of 589.3 millimicrons. Testing was performed in two stages which will be described later.

All subjects on flying status must have passed the Dvorine, AOC plates, Hardy-Rand-Ritter, or Farnsworth Lantern prior to initial flight training. This uncertainty as to type or previous test reflects the changes in test requirements over the previous two decades. It was also decided to include non-fliers in the study for comparison purposes. It was expected that the incidence of non-fliers classified as anomalous would be much greater than fliers because of their less stringent color vision requirements. Presumably only normal subjects would constitute the flier population as a result of examinations prior to acceptance for aviation training. In view of the validity measures reported on the tests cited above, and the waivers granted to trained pilots that slipped by the color testing plates for years prior to detection, we were certain we would have some color anomalous pilots.

In this study right and left eyes were tested separately. Since it is not customary to test the color vision of each eye separately it was our opinion that significant dissimilarities between the two eyes may have been overlooked in previous studies of this type. The potential theoretical value of a unilateral defect, having been previously reported by Judd in 1948[10] and later by Graham and Hsia,[11, 12] seemed another cogent reason to conduct tests in this manner. Our total sample of 2,000 subjects, 1,000 fliers and 1,000 non-fliers, revealed one subject (a senior aviator with over 20 years of accident free flying) who did, in fact, have a much more severe defect in one eye than the other. This subject matched a pure green with yellow and identified both as brown with one eye, and with the other eye properly named the colors yellow and green. Further work with this particular deutan subject is necessary to clarify his degree of anomaly.

The testing was accomplished in two phases. In phase one the anomaloscope test was given to all flying and non-flying personnel receiving other than Class 1 or initial flight status physical examinations. Those subjects classified as anomalous and selected for retesting were then retested in a manner to be described later.

In an effort to facilitate employment of the anomaloscope in the initial stage of the study, the yellow slit was fixed at a scale setting of 15 (an average normal brightness setting), and each subject was required to match the color of this brightness setting of the yellow by adjusting the single control which controlled the red-green mixture following 10 seconds fixation upon the adaptation light of the anomaloscope. Rather than determining the anomalous quotient, it was suggested by Schmidt[13] that it is better to give the original data and list the corresponding mean normal match. The scale value of 40 was selected as a normal match since it was the mean of 2,000 subjects (0 = pure green: 73 = pure red) on our instrument. Subjects were considered to be anomalous in this portion of the study if the red-green scale value for either eye was above 47 or less than 33. The results are shown in Figures 1, 2, 3, and 4. Ordinate values are frequency, and the abscissa represents the red-green dial setting. This criterion resulted in the selection of 14.2 percent of the fliers as anomalous versus 16.4 percent of the non-fliers as anomalous. This is indeed a tremendously high selection rate and is biased to select borderline normals as well as anomalous subjects. In order to make a more meaningful classification based upon a more controlled testing condition the subjects who were originally selected as anomalous were scheduled for retesting. In view of the distribution of this data it was decided to limit the retesting to those subjects on flying status.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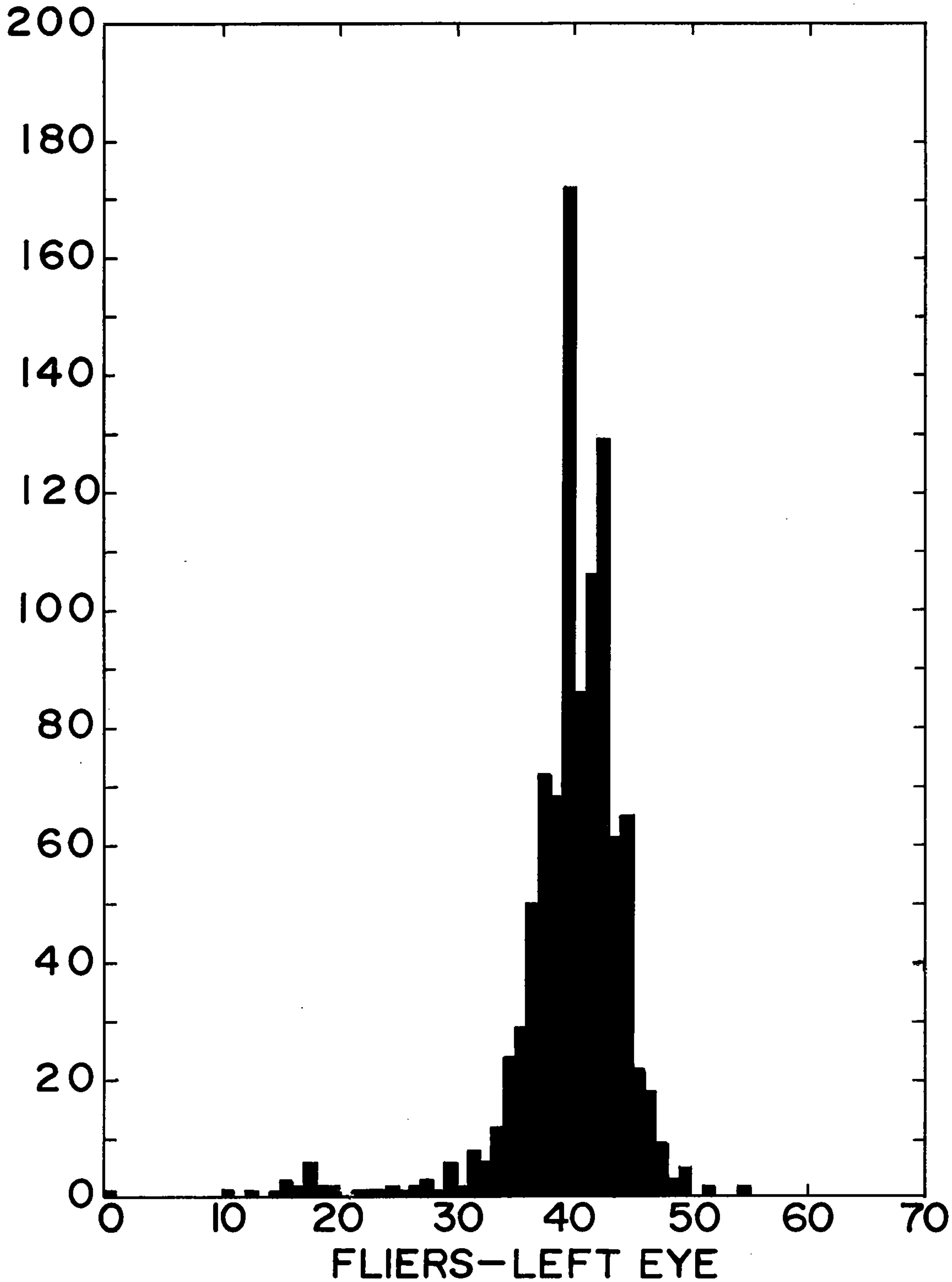
FLIERS-RIGHT EYE

FIGURE 1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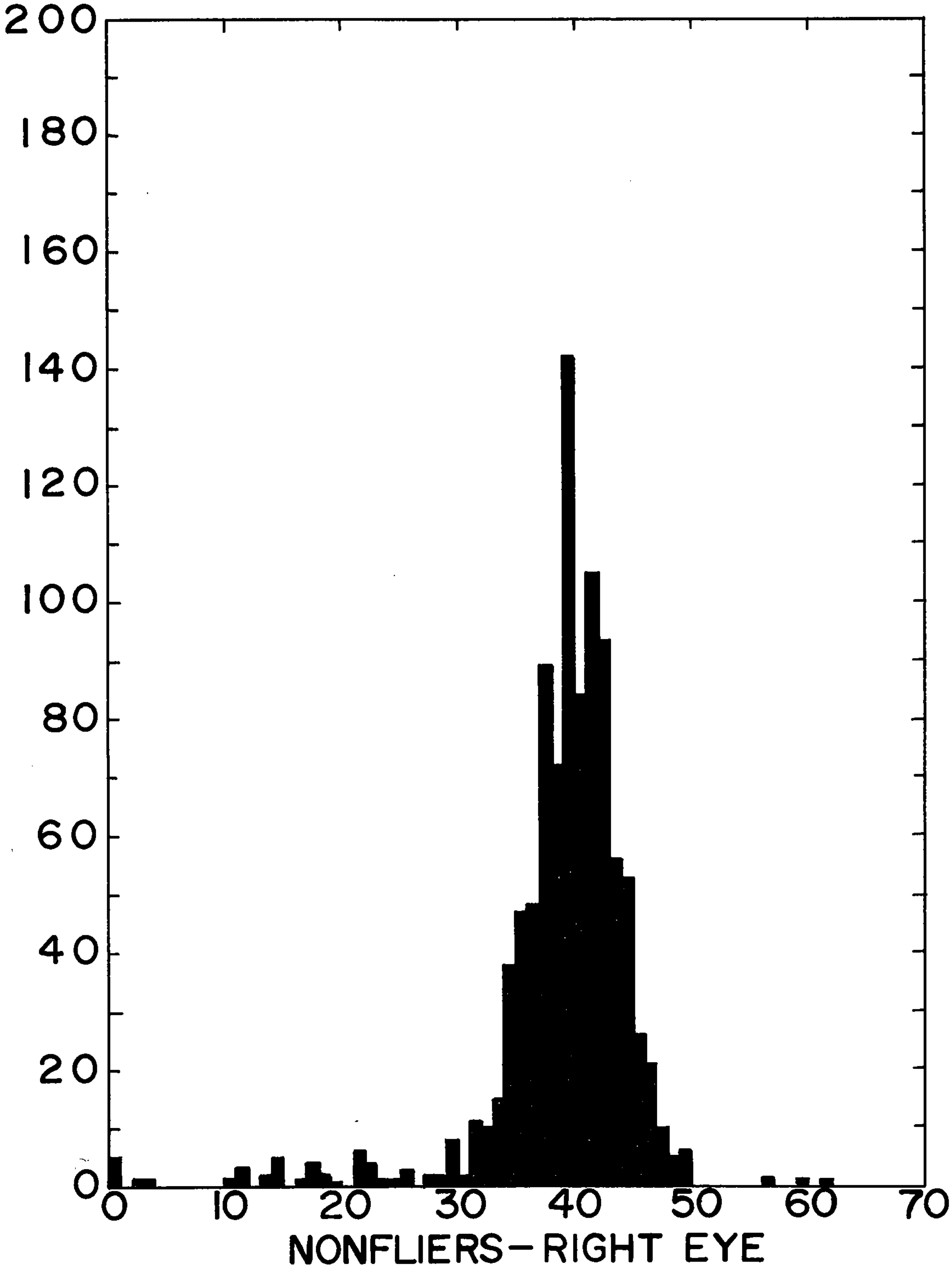
FLIERS-LEFT EYE

FIGURE 2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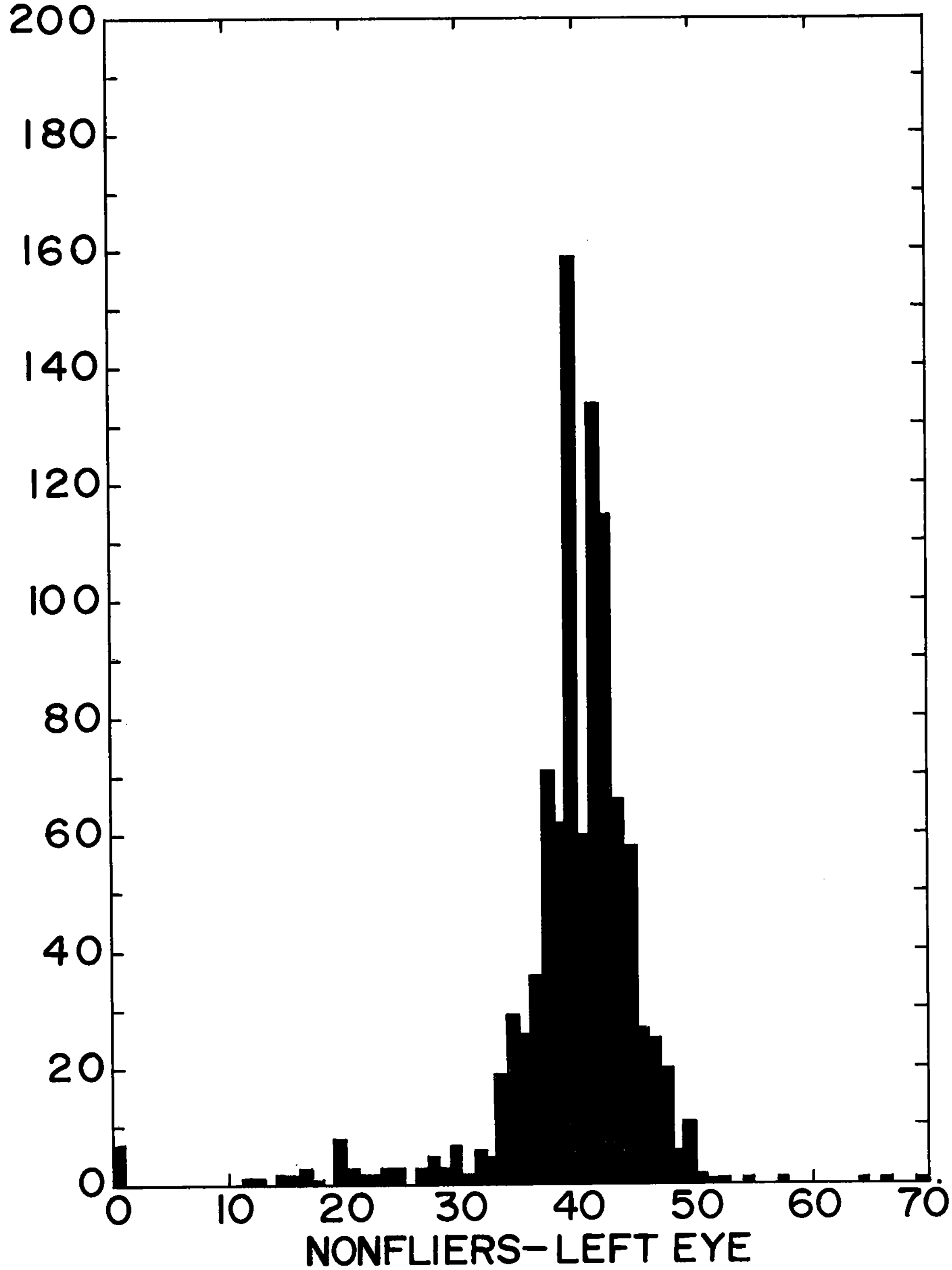
NONFLIERS—RIGHT EYE

FIGURE 3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NONFLIERS-LEFT EYE

FIGURE 4

Due to transfer and other administrative reasons only 82 subjects who were in the original sample, on flying status and classified as anomalous, were available for retesting. Of the 82 subjects, 73 volunteered for retesting and were retested; three were on temporary duty elsewhere, and six deferred or delayed reporting for testing until it was too late to be included in this report. It is the opinion of this researcher (since the anomaloscope results of the original test were such that little doubt existed concerning their anomalous classification) that these few subjects were reluctant to volunteer for further testing because they were afraid that their performance might interfere with their retention on flight status.

The retesting on the selected sample of the 73 subjects on flying status and originally classified as anomalous was done as follows:

1. Color matches following ten seconds fixation of the adaptation light were required for each eye with the yellow dial position set at 15 (the same as the initial testing). In view of the random setting of the red-green dial in the initial test these matches were made starting from 0, or pure green and from the 73 position, or pure red. This was done to see if the starting point setting of the red-green dial and the relative color difference from the yellow to be matched could have had an influence upon the scores. Adaptation effects on anomalous observers have been reported previously[14] but it was unexpected that this great an effect could result by merely starting the match from the red or green end of the scale. (Figures 5, 6, 7, and 8). This could be explained as the result of anomalous subjects susceptability to adaptation as is the case in the acceptance of a new, or deviation from an old, match after such exposure. The normal observer on the other hand is "reliably unchangeable".[15]

2. With the red-green scale at zero (pure green), brightness was required to be matched and the colors of the upper and lower halves of the field named after the match was completed. Only one of the subjects failed to identify the colors correctly, but this was only in one eye.

3. With the red-green scale at 73 (pure red), the same information as in 2 above was obtained. All subjects identified the colors in both halves of the field correctly with each eye.

4. With the red-green scale at 40 (mean normal match), a brightness match was made between the upper and lower portions of the bipartite field. All subjects were able to make this brightness match.

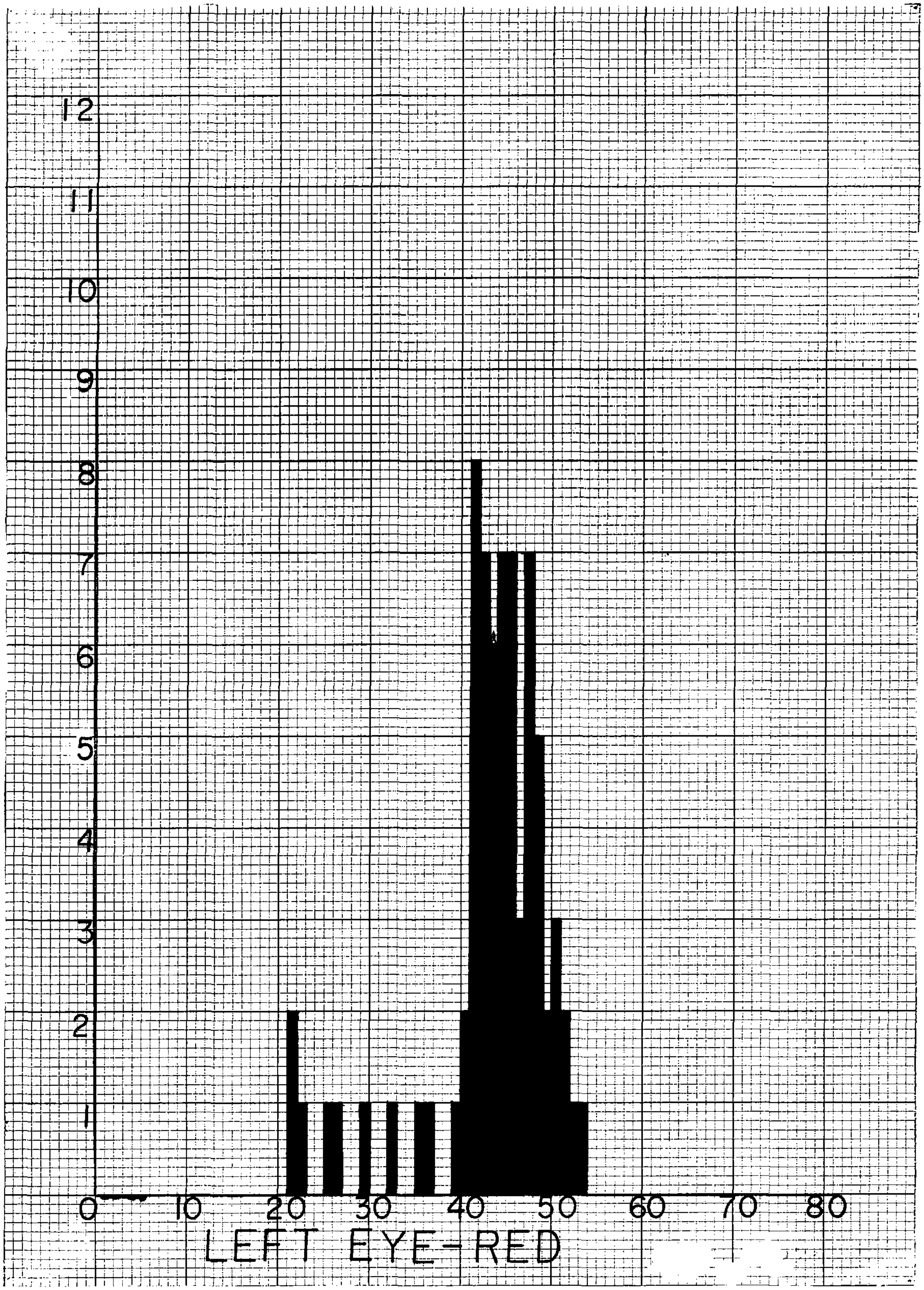


FIGURE 5

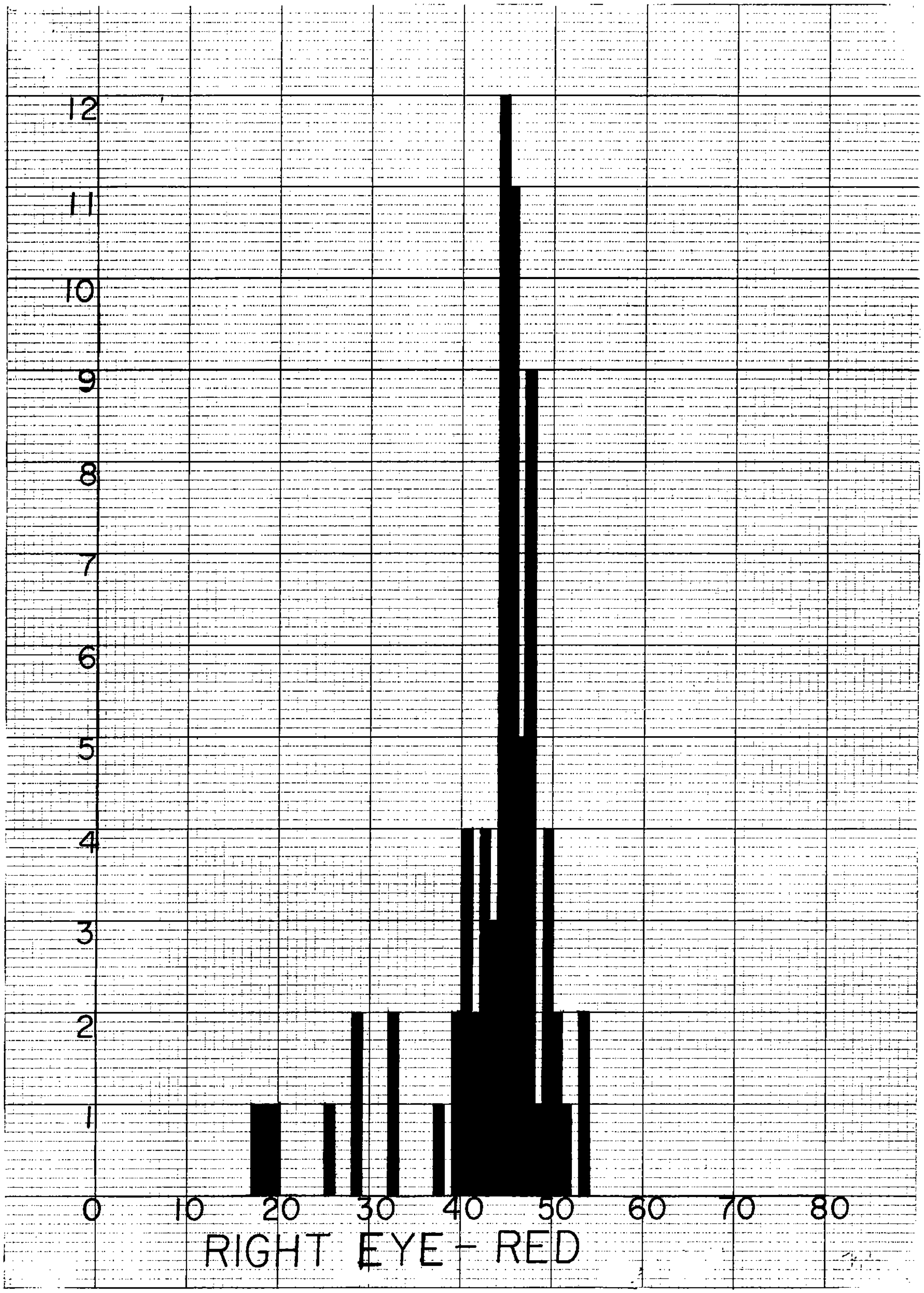


FIGURE 6

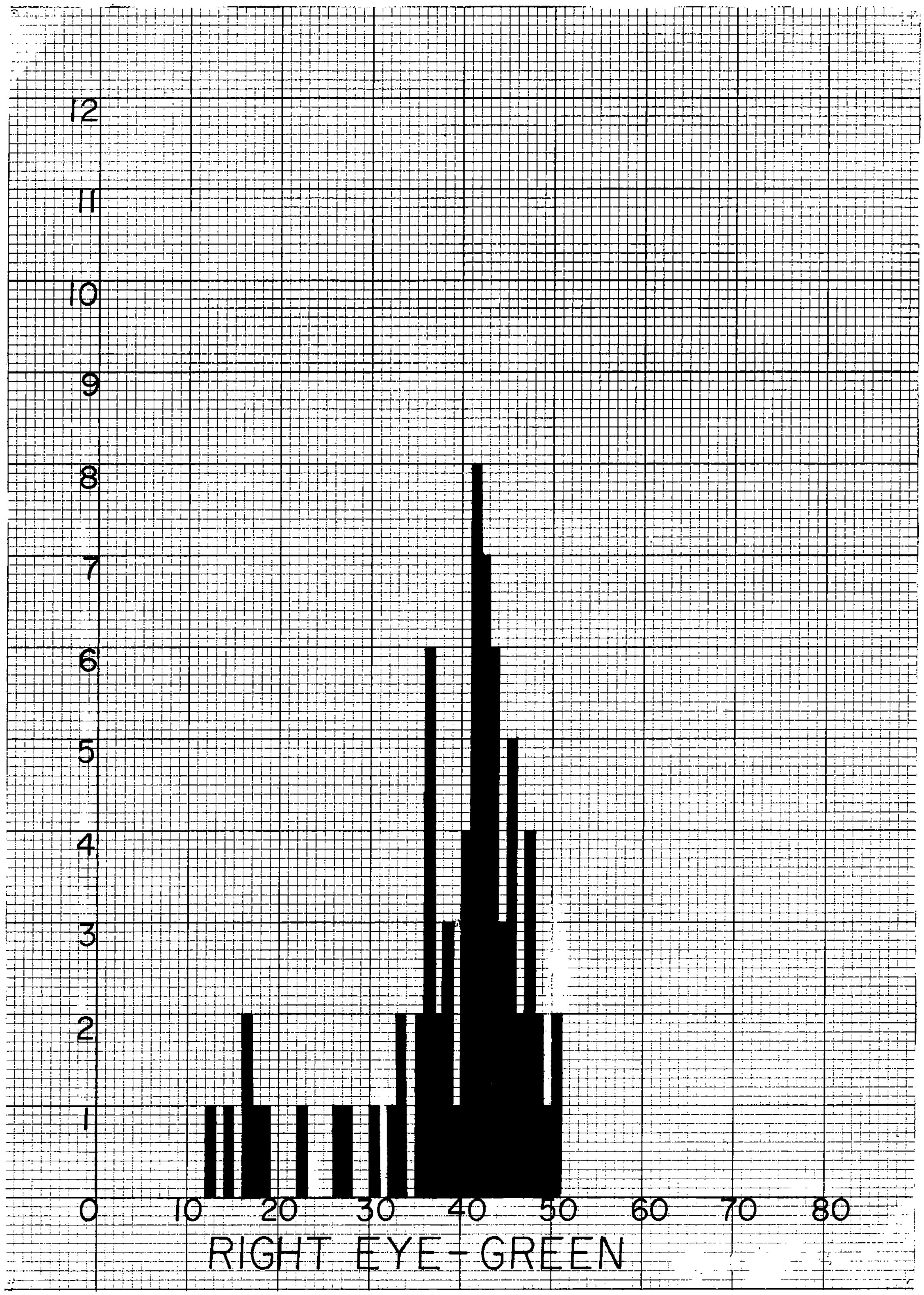


FIGURE 7

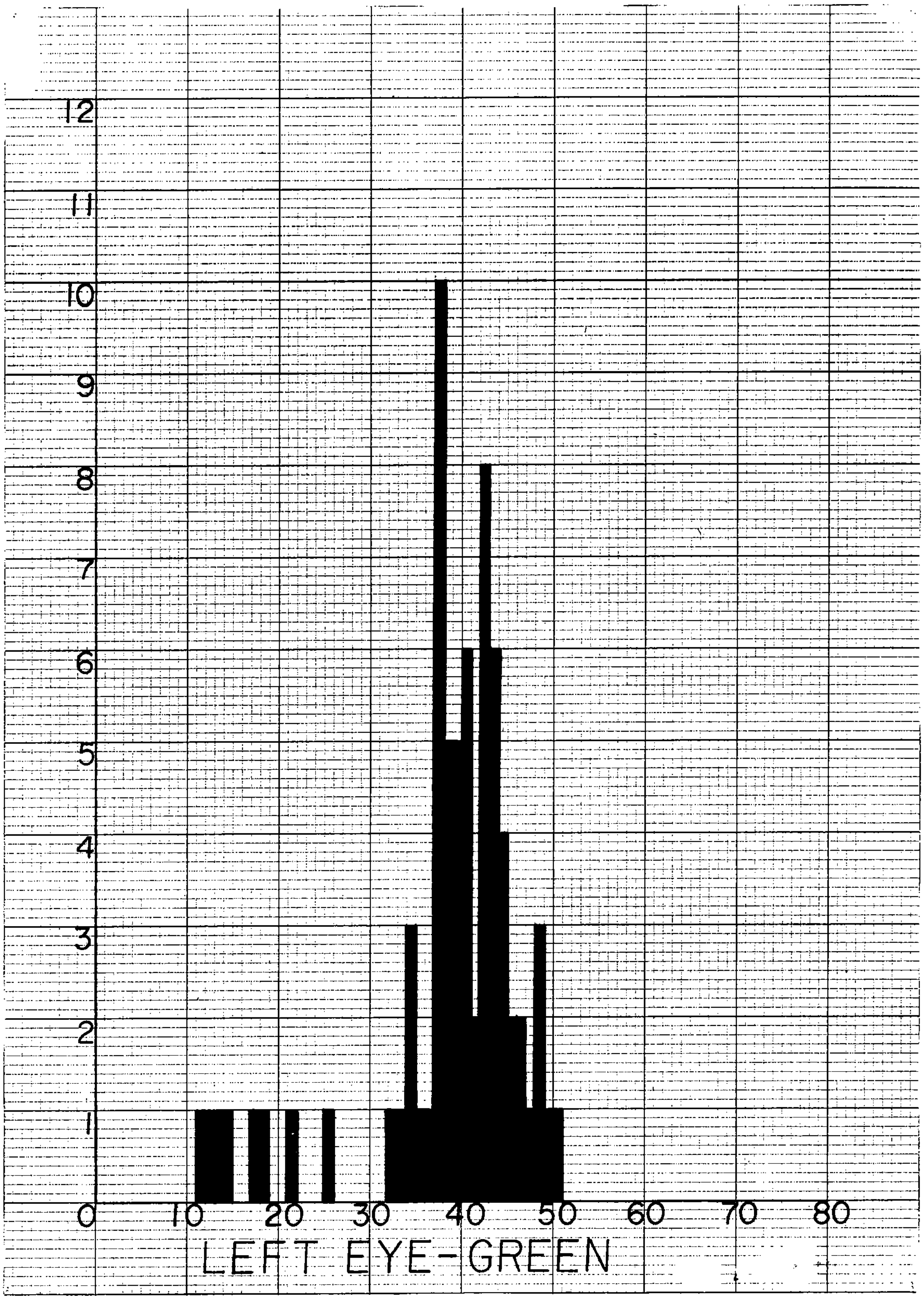


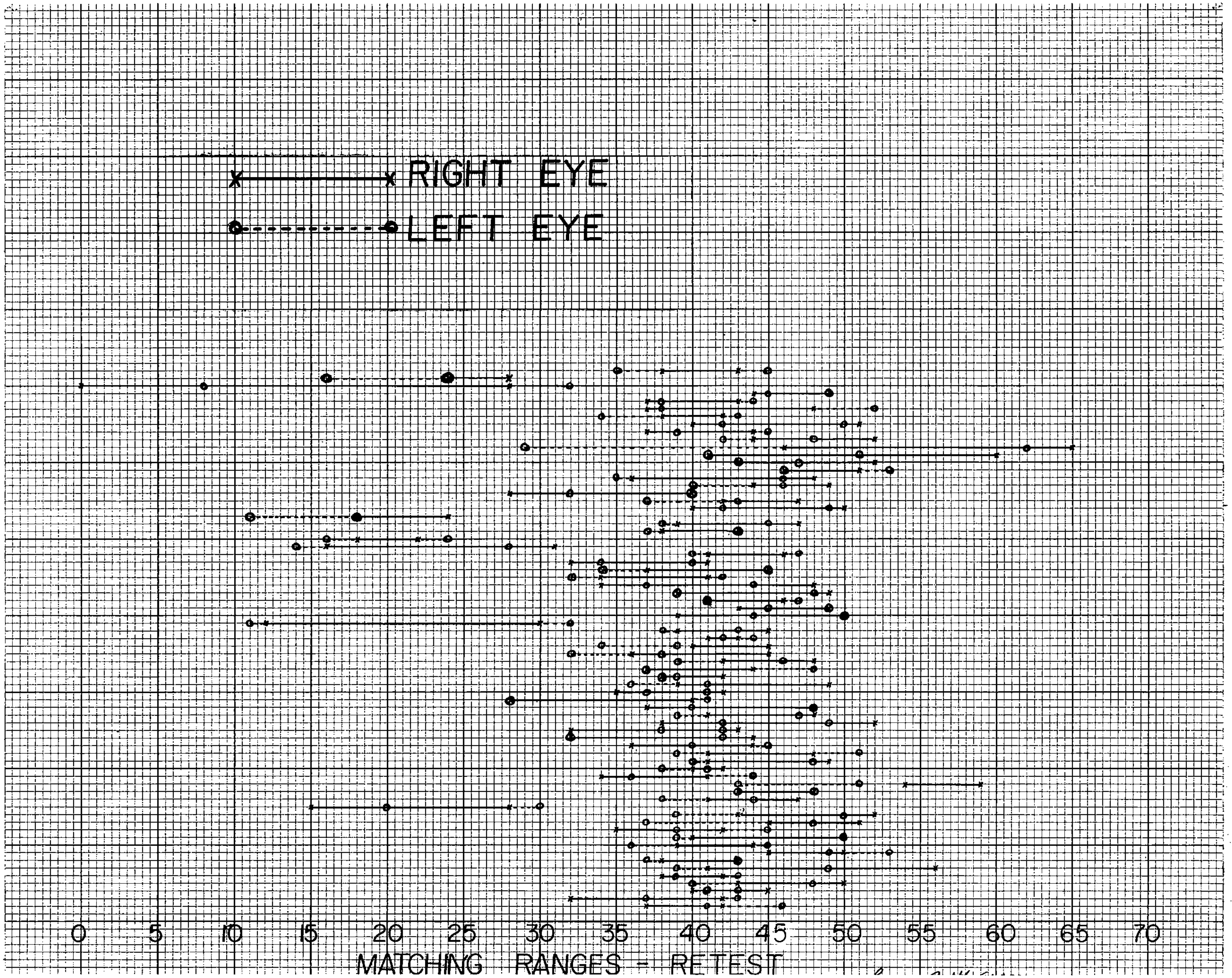
FIGURE 8

5. With the brightness match setting as determined in 4 above, a color match was made by adjustment of the red-green control knob. Immediately after this match the subject adjusted the red-green control knob until the upper half of the field was just noticeably too green and then back in the opposite direction until the upper portion was just noticeably too red to match the yellow in the lower half of the field. This established the range of match scores. (See Figure 9).

The normal range of mixtures for considering the retest data was ±7 dial units either side of the normal mean. Engelking[16] recommended that the range be ± 3 dial units, however his recommendation was based upon an anomaloscope with a normal mean of 60. This represents anomalous quotients of .65 at a dial setting of 64 and 1.4 at a dial setting of 56. In order to compare this criterion to our anomaloscope with a normal mean of 40, equivalent anomalous quotients were calculated which resulted in dial settings of 34 and 47. Therefore the ± 7 dial units provides a criterion that is almost identical to Engelking. This also compares with Schmidt's[17] criterion in which she employed a statistical range of 3σ.

The above criterion was applied to the 73 retested fliers and rejects 17 as either protanomalous or deuteranomalous and an additional 6 subjects who were borderline, but had a range of greater than 10 dial units which classified them as anomalous. This constitutes a total of 23 subjects of the 73 retested fliers, or approximately 32 percent. This percentage applied to the original 14.2 percent originally rejected would indicate that we could predict that approximately 4.5 percent of our flying population can be considered as having anomalous color vision.

In summary, our original testing technique was only about 32 percent effective in identifying anomals. However, it is also evident that our flying population has a number of fliers with anomalous color vision. It also indicates that the tests employed in the past have only been about 25 percent effective in eliminating those with anomalous color vision. This is derived from the 4.5 percent of our aviator population as compared to the general male population incidence of anomalous color vision which is 6 percent. It is of interest to note, however, that only one of our subjects could be considered as deuteranopic and then only in one eye. Therefore, the color vision testing of Army


RIGHT EYE
LEFT EYE
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MATCHING RANGES - RETEST

FIGURE 9

aviators appears to have been effective in preventing deuteranopic or protanopic subjects from being accepted into aviation training. The fact that the incidence of anomalous color vision among Army aviators is as large as we have found it to be serves to reinforce our interest in the role of this anomaly in selection, training and the flying safety of Army aviators.

REFERENCES

1. Bouman, M. A. and Walraven, P. L. "Some problems in testing color vision", Collected papers on aviation medicine, Butterworths Scientific Publications, London, 1955.

2. Bouman, M. A. "Selection for color naming of air traffic lights and reading of radio resistances color code", Institute for Perception, Soesterberg, Netherlands.

3. Heath, G. G. and Schmidt, I. "Signal color recognition by color defective observers", Am. Jour. Opt. and Am. Acad. of Opt., Monograph 260, August 1959.

4. Dimmick, F. L. and Foss, C. E. "Factors in the application of the color aptitude test", Official Digest, 26, 1954 (Dec).

5. Walraven, P. L., Leebeck, H. J., and Bouman, M. A. "The I.S.C.C. Color Aptitude Test, The Interpretation of Some Testing Results", Report WW-1956-10, Institute for Perception, Soesterberg, Netherlands, 1956.

6. Collins, W. E., Casola, A. S., and Żegers, R. T. "The performance of colorblind subjects on The Color Aptitude Test," Jour. of Gen. Psych., 64, 245-250, 1961.

7. Verrey, A. and Wolffin, E. "Die Farben sinnprufung und unsere eidengenossichen Verwaltung," Schweiz Opth. Ges., 71, 228, 1923.

8. Trendelenburg W. and Schmidt, I. "Untgrsuchungen uber Vererbung angeborener farbenfehlsichtigkeit", Sitz. Preuss. Akad. Wiss., Phys.-Math. Kl., 2, 13-81, (1935).

9. Willis, Marion P., and Farnsworth, D. "Comparative evaluation of anomaloscopes," Medical Research Laboratory Report 190, US Naval Submarine Base, New London, Conn., 1952.

10. Judd, D. B. "Color perceptions of deuteranopic and protanopic observers," Journal of Res. of Nat. Bureau of Standards, Res. Paper RP 1922, Vol. 41, Oct. 1948, page 247.

11. Graham, C. H., and Hsia, Y. "Luminosity curves for normal and dichromatic subjects including a case of unilateral color blindness," Science, 120, 780, 1954.

12. Graham, C. H., Hsia, Y., and Berger, E. "Luminosity functions for normal and dichromatic subjects including a case of unilateral color blindness," Journal of the Optical Society of America, 45, 407, 1955.

13. Schmidt, I. Personal communication.

14. Bailey, R. W. "The effect of chromatic adaptation on color blind observers," Am. Jour. of Optometry and Archives of American Academy of Optometry, Vol. 37, No. 10, 1960.

15. Linksz, A. "An essay on color vision," Grune and Stratton Inc., New York, 1963, page 193.

16. Engelking, E. "XIV Concilium Ophthalmologicum Hollandia IV, 4, page 55, Amsterdam, 1929.

17. Schmidt, I. "Some problems related to testing color vision with the Nagel anomaloscope," Jour. Opt. Soc. of Amer. Vol. 45, No. 7, pages 514-522, July 1955.